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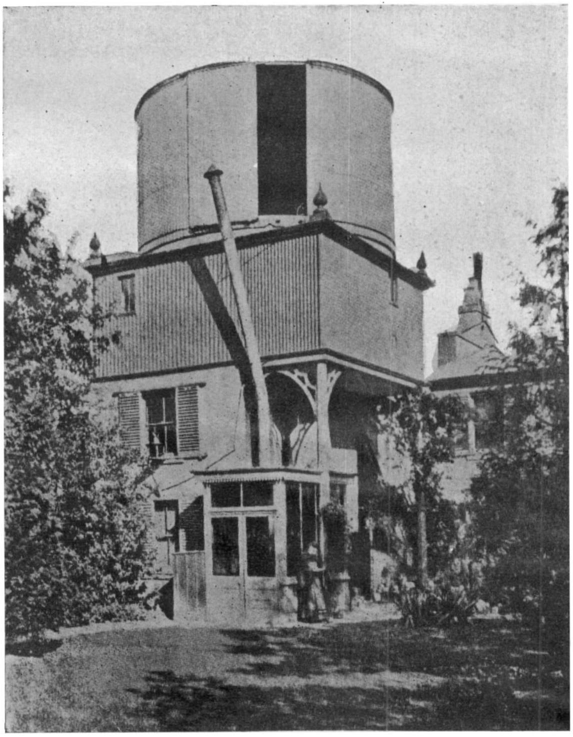

Sir William Huggins' Observatory, Upper Tulse Hill, London.

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WORK FOR THE AMATEUR ASTRONOMER.

By George Ellery Hale.

I. *Introduction*[1]

No chapters in the history of science are more inspiring than those which recount the deeds of the amateur. Hampered, it may be, by lack of equipment, situated where the conditions for research are not of the best, and often compelled to devote his best hours to other pursuits, the amateur, rising above all discouragement, has continued to pour a flood of new ideas and significant observations into the ever-widening sea of scientific knowledge. Many a great name is associated with a modest beginning, and many a discovery has been made with inexpensive apparatus. Galileo and Newton, during their boyhood days, foreshadowed in their model windmills, water-clocks and other mechanical contrivances the latent ability which ultimately found full expression in the first refracting and reflecting telescopes and in other instruments and researches. Bessel, an apprenticed clerk in a German mercantile house, began his astronomical career by measuring the longitude of Bremen with the aid of an ordinary clock and an improvised sextant of his own design. Herschel, the organist of Bath, after constructing a 2-inch telescope, built for himself larger and larger instruments, and made contributions to every department of astronomy. Schwabe, the apothecary of Dessau, recording sun-spots from day to day for forty-three years with his small but "imperturbable telescope," discovered that their number waxes and wanes in the now well-known sun-spot period. Carrington, following Schwabe's example in his little observatory at Redhill, found that spots near the equator are carried westward more rapidly by the solar rotation than those in higher latitudes, and accumulated a great volume of valuable drawings and sun-spot statistics which are still in constant use by astronomers. Lassell, an English brewer, and Bond, who began his astronomical work while carrying on his trade in Maine as a watchmaker, discovered *Hyperion,* the seventh satellite of *Saturn,* on the same evening. Burnham, engaged throughout the day in the Chicago law-courts, spent his nights in observation with a 6-inch telescope, and discovered nearly five hundred new double stars. Huggins, undaunted by the smoke and fog of London, demonstrated at his Tulse Hill Observatory the gaseous nature of nebulæ and laid the foundations of the observational study of stellar evolution. Such illustrations might be given in large numbers from the records of astronomy, and multiplied many fold from the general history of science. They would include such notable cases as Darwin, whose work was done with the simplest of means, largely in the quiet of his home and undisturbed by the trend of contemporary thought; Faraday, the blacksmith's son and bookbinder's apprentice, essentially without education except the little derived from Davy's popular lectures on science at the Royal Institution; and Lord Rayleigh, who prefers his home workshop, with its simple facilities, to the extensive equipment of the Cavendish Laboratory.

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[1] This is the first of a series of articles by Messrs. Hale and Snow, which will explain how to build a small coelostat telescope with various accessories, and describe a series of observations and experiments in solar physics.

But neither in limited or unlimited resources nor in association with public or private laboratory do we find the criterion that marks the amateur. Nor is he to be mistaken for the dilettante of the popular imagination. The amateur is in fact a true lover of knowledge for its own sake, one who works because he cannot help it, swept on by a passion for research which he attempts neither to explain nor to curb, an enthusiasm which carries him over obstacles too high to be surmounted by the perfunctory student or the man without zeal. To the sane enthusiast, whether his talents be large or small, great advances are possible. An impelling interest, even if backed by only a very slender stock of knowledge, may accomplish more than all the learning of the schools.

While it is fortunately true that the amateur, in professional guise, is often found in the great university laboratory or the endowed observatory, he usually begins his work at home and without expensive appliances. The passion for research springs early, and the boy of twelve may already feel within him the desire to add to the world's knowledge. He consults his books, and is fascinated by the experiments they outline. Who can forget his thrill of excitement when the bubbles of oxygen, issuing from the heated retort, rose one by one thru the water-filled bottle, inverted over its tank! The delicious possibility of an explosion (realized all too often with prematurely ignited jets of hydrogen!) and the proud consciousness of actually venturing into the field of the original investigator, are experiences to be felt but not described. Then there was the winding of the first induction coil, the anxious test of the length of its spark, and the dim realization that here was an instrument of research applicable in many fields. In another province the return of spring and the breaking of the ice in the ditches meant exciting pursuits of the wily Cyclops and the agile Branchipus, or the lesser forms of life in the marvelous world of rotifers and vorticellæ. In recent years, as I have pushed with larger and larger telescopes into the depths of space, I have often been forced to confess that the astronomer never beholds sights more wonderful than those which a drop of ditch-water, on the stage of the cheapest microscope, will afford to any boy.

But while the observation of natural objects, the collection of specimens, or the performance of simple experiments may content many beginners, there are those who yearn to advance into the actual work of original research. To them, and perhaps to others, a series of connected experiments or observations, sufficiently varied to be attractive, but so contrived as to lead step by step into some profitable field of investigation, should be more interesting than the isolated phenomena more commonly described. If properly chosen, such experiments may serve as an introduction to the methods of the investigator and a stimulus to individual effort. By suggesting the unbounded opportunities for discovery which lie open in every department of science, they may also encourage the beginner to undertake a serious study of his subject and thus to prepare himself fully for the work of investigation.

What, then, does the beginner in science need? Judging from my own experience, I think he should first feel the stimulus which comes from reading of the great discoveries in any field of science, in the words of the discoverers themselves. These will inspire him to work, and convince him that knowledge is not a sealed book but an open manuscript, to which he may hope to contribute paragraphs or even chapters. He must learn of the many ways in which advances may come: by long-continued observations, carefully discussed; by the quick application of new ideas to the interpretation of old phenomena; by the invention and use of new instruments; by increased precision of measurement; by the recognition of relationships between seemingly unrelated things. He must be led to see that important discoveries do not necessarily demand expensive instruments, but result quite as often from the skillful use of the simplest means. He must realize that he, like others before him, can improvise these means, and apply them in real research. He must learn to cultivate an open mind, skilled in the art of devising explanations of his observations, but free from the prejudices which surround the man of one idea. He must know of the many laboratories and observatories where research is in progress, and become familiar with that great company of investigators who even in these days of war continue to widen knowledge. And in doing these things he must bear in mind that while he, too, may hope to join this company, he can do so only by showing good sense and good judgment, publishing no results until they have been amply verified, and adopting every possible means to extend his education and widen his experience.

To the would-be investigator, dimly perceiving for the first time the boundless possibilities of original research, there is no such stimulus as that to be derived from direct contact with the masters of his subject. He should not be content with some second-hand description of their work, but go straight to the original sources, and read what was written in the very heat of progress. Thus he may feel with them the dawning consciousness of new lands to be explored and experience some of the delight which they felt when they first passed from the known into the unknown. Moreover, he may best realize in this way how simple are the tools so often employed to attain the most important ends, and recognize the advantage of cultivating an alert and optimistic mind, sensitive to new impressions and aware of the opportunities which are ever open to the ready inquirer.

Having made a brief survey of his subject, which should be followed by wide reading in the classics of science and in its extensive periodical literature, the beginner will wish to try his own hand. Let us suppose him to have chosen the field of astronomy. First of all he will be fascinated by the stars and by the many problems they offer for solution. The vast extent of the universe, the beautiful phenomena of star-clusters, nebulæ and comets, the changing light of the variable stars, the surface markings of the Moon and the planets—these and many other phenomena will appeal to his imagination and to his instinct for investigation. Last of all, perhaps, he may realize the unique opportunity for widely varied study which the Sun affords, and understand why this is so. For all the other stars are very far away—so far that they appear merely as needle points of light in the most powerful of telescopes. To see them as we see the Sun, to discern their huge disks, the spots on their surfaces, the flames in their atmospheres, we must approach them closely, and there is no prospect that any telescope, however powerful, will ever make this possible. They remain, under the highest magnification, as extremely minute points of light.

How fortunate, then, that one star is so near at hand! This one exception, our own Sun, is proved in a score of ways to be a perfectly typical star, similar in chemical composition, in size and in structure to millions of other stars in the remote distances of space. It is so near us that any telescope will show its disk and the spots that come and go on its surface. These and its other phenomena are most varied in character, constantly changing in number and in form and suggesting problems of every kind for solution. With simple instruments, easily constructed, they can be brought within the amateur's range. If fortunate enough to have access to a small shop, he can build his own telescope, procuring the optical parts at very slight expense from the nearest spectacle maker. If not, he may employ a local machinist to do the work which is beyond his capacity.

Once constructed and installed, the telescope will be ready for work of real value, as it will yield photographs of the Sun suitable for such studies as those of Schwabe and Carrington. But the young solar physicist, who has read of the marvelous discoveries of the spectroscope and its almost unlimited possibilities when applied to the study of the Sun, will not rest content without the support of this powerful ally. Indeed, he will have realized that the spectroscope is even more important in solar research than the telescope itself, tho the combination of the two is usually essential. Thus he should proceed to complete his outfit by constructing a spectroscope, which may advantageously take the form of a spectroheliograph, since this instrument can be used both as a spectroscope and as a means of photographing the invisible phenomena of the solar atmosphere. Fortunately this apparatus is extremely simple and inexpensive, and can easily be built by the amateur himself.

Thus equipped, the amateur astronomer is prepared for a long series of fascinating observations. He will first wish to repeat Kirchhoff's epoch-making discovery, and prove the existence of sodium and iron and other elements in the Sun. This experiment can be made visually, but the photographic method is far more satisfactory, and should be applied without delay. Nothing is more striking than to see a long strip of the solar spectrum recorded on the photographic plate, side by side with the hundreds of bright lines of the iron spectrum, each of which has a solar counterpart. The amateur will at once realize the certainty of spectrum analysis, and understand how Rowland, testing substance after substance against the Sun, finally identified a large majority of the terrestrial elements as glowing gases in the solar atmosphere.

Thus made acquainted with the gaseous surroundings of the Sun, he will wish to observe their remarkable forms. Ordinarily concealed by the brilliant light of the sky, the red solar prominences rise high above the disk of the Sun when it is obscured by the Moon in a total eclipse. But we need not wait for one of these rare events, as Janssen and Lockyer showed in 1868 how a spectroscope can be used on any clear day to render these flames visible. Having watched their changing forms and studied their spectra, the amateur will wish to photograph them, which he can easily do with his spectroheliograph. And this will lead him to take another step.

It is evident enough that the chromosphere and prominences which we always observe on the solar circumference must also exist on the disk of the rotating Sun, tho concealed by its brilliant light. If we photograph the spectrum of the disk, we find the dark H and K lines of calcium to be brightly reversed in irregular patches, which are most extensive in regions surrounding sun-spots. To photograph the forms of these luminous clouds of calcium vapor (the flocculi), we set the H or K line on the camera slit of the spectroheliograph, and move this instrument slowly across the solar image. A series of photographs made in this way will provide the means of studying the structure and changes of the calcium vapor at different levels in the solar atmosphere.

Thus, aided by laboratory experiments with home-made apparatus for the interpretation of the solar results, the beginner should be fairly started in the field of astrophysics. Later, if he should wish to extend his equipment, he can acquire instruments powerful enough to permit the photography of solar vortices, and the study of the solar rotation, the pressure and motions in the solar atmosphere and the magnetic fields in sun-spots.

A brilliant Sun shines overhead, and the air is fragrant with the odor of orange blossoms on this February afternoon in Southern California. Yet I am forcibly reminded as I write these lines of a dark winter's day in Chicago some thirty-five years ago. I was reading "The Amateur Mechanic's Workshop," and even now I can feel the thrill of excitement which came with the sudden resolve to follow the example set in the book. The young mechanics of an earlier volume had begun the construction of a workshop, which was fully described and illustrated. Why should I not build one myself? The snow lay deep on the ground, and weeks of winter were yet to come. Clearly it was too soon to begin work out-of-doors. But the resolve had been kindled, and its impulse would not be quieted. I could already see the shop completed, with its long benches equipped with vises and tools, and my recently-acquired lathe (which had a small slide-rest, and would actually turn metal!) standing in the place of honor. Indeed, the lathe seemed suddenly to have acquired an overhead attachment for driving milling cutters and other accessories resembling those pictured in the books of Holtzapfel and other English authorities of the day. I could hear in imagination the hum of a small steam-engine, the castings for which had arrived on Christmas Day, and see it driving the cutters in the pleasantest manner in the world!

Surely such a dream must come true, snow or no snow. So I at once began work on the scale drawings, trudged thru the snow with my small sister and brother to the lumber-yard, and invested my slender savings in water-soaked 2 x 4's. Hauling these home on our sled was a heavy task, but when they were finally there we lowered a rope from the narrow window of a dark and lofty attic, and hoisted them up into its friendly shelter. Here the work of framing was pursued after school hours and on those joyful Saturdays, and before spring had really come the dismantled skeleton was lowered to the ground and the work of erection begun. Finally the shingles were all laid, and we looked with satisfaction upon our combined shop and laboratory. Tho only ten by fifteen feet in size, it gave us immense pleasure and prepared the way for later buildings of more ambitious kind.

Such memories have led me to write these pages. I have lost none of my respect for the books of my boyhood, or for the new ones which have been published since. But I hope that the actual experiences of a boy groping his way toward original research may have taught me something of the needs of others, and of practical methods of meeting them. Fortunately I have been able to enlist the collaboration of another amateur, Mr. Lorenzo Snow, whose acquaintance with present sources of optical and mechanical supplies is wide and varied. Mr. Snow will make working drawings of the instruments embodying our joint ideas, and describe the details of their construction. Our plan will be to utilize standard optical and mechanical parts, everywhere obtainable at very small cost from spectacle makers and dealers in machinists' supplies. In building the apparatus we do not intend to utilize the workshops of the Mount Wilson Observatory or others similarly equipped, but will rather depend upon the services of machinists and carpenters such as are found in every small town. In this way we hope to show how an amateur can have equally good instruments built almost anywhere, if he cannot adopt the far more satisfactory plan of making them himself. The papers will conclude with a series of experiments and observations designed to illustrate the use of the spectroscope and spectroheliograph and to serve as an elementary introduction to solar research. If they should succeed in convincing some serious beginner that the pleasures of his holiday hours may well be continued thru the whole of an investigator's life, they will accomplish the object for which they are written.

A SPECTROSCOPIC METHOD OF DETERMINING STELLAR PARALLAX[1]

By Walter S. Adams.

The absolute magnitude of a star is defined as its apparent magnitude when reduced to unit distance, and may be calculated, when the distance is known, from the simple relationship

$$M = m + 5 + 5 \log \pi$$

In this equation M is the absolute magnitude, m the apparent magnitude, and π the parallax. It is evident that if some means exists by which M may be determined directly this expression will in turn provide a determination of the parallax.

The question whether the absolute magnitude of a star may not have a material influence upon the character of its spectrum is one which has been discussed to a considerable extent in recent years. It appears probable from investigations made at Mount Wilson that the intensity of the continuous spectrum is affected to a marked degree by the luminosity of the star; and such a result is rather to be expected when we consider that if two stars have closely the same type of spectrum but greatly different luminosities they probably differ greatly in size, in mass, and in depth of the atmospheres surrounding them. Such a marked difference in physical conditions would be almost certain to influence the intensity of the continuous spectrum, and we might even hope to find in the line spectrum of these stars certain variations in the intensity and character of such lines as are peculiarly sensitive to the conditions in the gases in which they find their origin.

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[1] Adapted from a series of papers published in the *Proceedings of the National Academy of Sciences*.